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AGV Design

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By

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Abstract

This report details the design and calculation work done towards creating an autonomous guided vehicle (AGV) for use in the steel and metal related industries. Steel Equipment Specialists (SES) is a major manufacturer of coil transportation vehicles for these industries. SES believes the future of coil transportation within the mills includes AGVs in some circumstances. The team was tasked with exploring the design and cost of a base model for use in future designs, since SES has not yet modeled or manufactured an AGV. This design was successful under the stress from the application in calculations, and the cost of the design was minimized, which resulted in a design which exceeded expectations. Safety was the most important factor for the team during design, and the safety features included should minimize injury due to machine design and function. Due to these accomplishments, SES considers the design successful.

Contents

1. Introduction

Steel and aluminum sheet metal is used for countless applications across the world. For transportation within a mill for production, as well as for transportation to the manufacturing facilities which use sheet metal around the world, the long sheet of metal is wound up on a mandrel into a coil. SES, the industry sponsor for this project, is a leading manufacturer in equipment for use in steel mills and similar industries, with particular experience with coil cars, which move these steel coils around a mill. Typically, coil cars run on rails only between a few points. Autonomous guided vehicle (AGV) transportation has the potential to increase productivity and reduce cost in mills by transporting coils to and from multiple locations. This group was tasked with determining the cost, feasibility, and basic design for SES to use as a basis in AGV production. The conclusion reached was that, for certain applications, an AGV would be more cost effective than traditional coil car designs used. This could lead to production of an AGV by SES in the near future.

2 Design

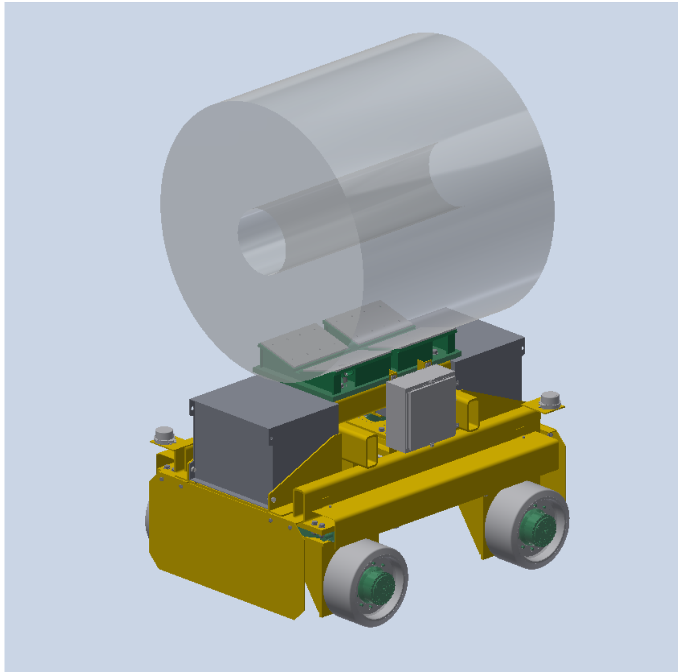


Figure 1- Full AGV Assembly

2.1 Drive

Figure 1 shows the complete assembly. The design process began with the drive components. Polyurethane wheels were selected because of their high load capacity, floor protection, and resistance to abrasion. Motors were then chosen to both drive and steer each wheel. The team had both types of motors quoted by Kraft Fluid Systems, a local company with years of experience of applying electric drives to AGVs. A wheel hub motor would directly drive each wheel and a rotational steer motor would be used to rotate each wheel independently. Four-wheel drive and four-wheel steering and would maximize performance, giving the car more control and allowing it to navigate uneven floors. A weldment was then designed to mount to each drive motor and steer motor on separate faces, ninety degrees apart. Lastly, a mounting plate was designed in order to connect each wheel assembly to the main frame. A model of the finished wheel assembly can be seen in Figure 2. In addition, appendix C contains a drawing of the completed assembly.

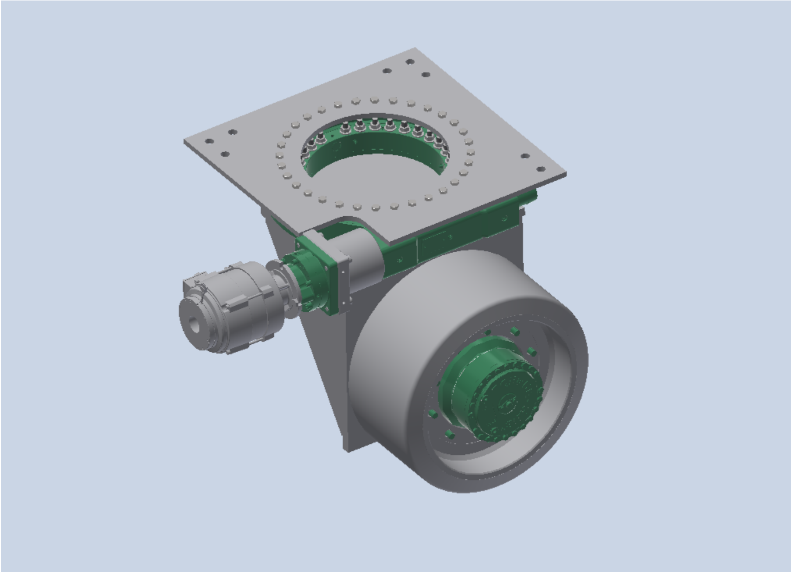


Figure 2- Drive Wheel Assembly

2.2 Frame and Coil Holder

The main car frame, the largest and most complex weldment of the car, was designed for heavy loads and made of commercially available structural steel shapes. The frame design allows the wheel assemblies to be fastened to the corners, a separate coil holder weldment on top, and places to mount various electrical components, including batteries, sensors, and the charging pad. The V-shaped coil holder was designed to handle the weight and various sizes of steel coils. Polyurethane liners are secured to the top constant points and a small coil detection sensor is mounted inside the weldment. The coil holder is mounted to the frame using large bolts and Belleville disc washer springs. This type of connection gives the car some suspension, while allowing for high loads. Models of the frame and coil holder can be seen in Figures 3 and 4.

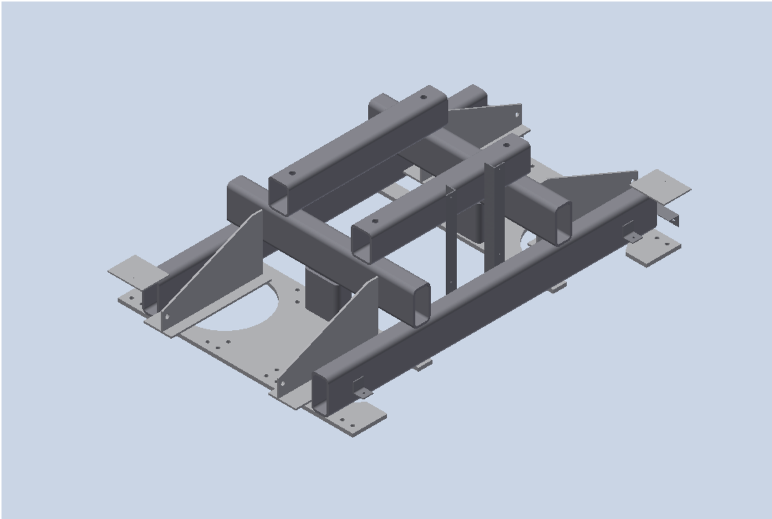


Figure 3- Frame

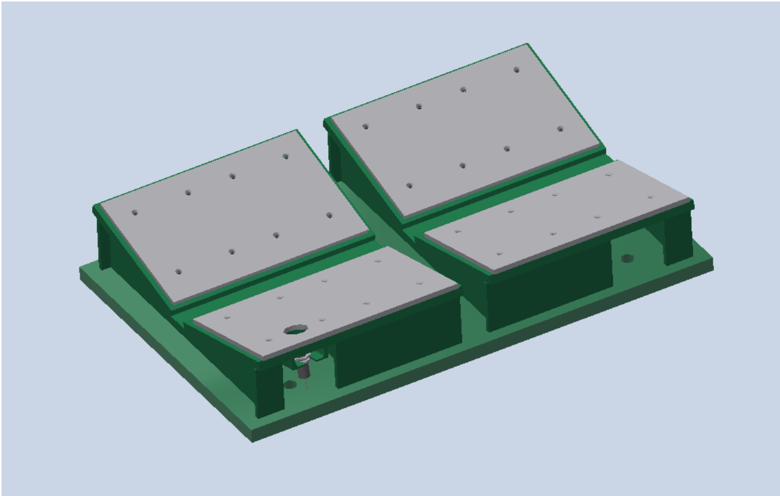


Figure 4- Platen, to Hold Coils

2.3 Electrical Components

2.3.1 Battery and Charging

Battery and charging system details can be found in appendix B. Charging system was selected to be able to quickly charge the batteries during rest periods, nearly to full charge. To charge, a charging station will need to be installed nearby, and a charging pad will need to be placed in the path where the car will be stopped. To improve charging in the future for an expanded functional area for the AGV, multiple charging stations can be installed.

2.3.2 Sensors and Safety

Many sensors are used on the AGV, for various purposes, particularly safety. Cameras mounted on opposite corners give the AGV a full view around itself. Each individual camera has a 270° view, and on opposite corners can combine to give a full 360° view. These sensors can be used to detect if a human or other obstacle is in the path of motion, which can give the signal to slow or stop the AGV. The AGV follows a magnetic strip, with a sensor attached to the bottom of the AGV to detect it. This sensor can detect a magnetic field of opposite polarity, as well as an RFID tag embedded in the ground at the end of the track. Another sensor is mounted on the platen, to detect the presence of a coil on the car. This will allow for further automation in loading of the AGV, and will help with data collection for analysis of the system.

3. Design Verification

Because this AGV would not actually be built, and prototyping would be impractical, most design verification was done through calculations and computer simulations. Stress analysis was vital to proving strength and durability in this high load environment. Finite element analysis software was used to conduct a portion of this analysis on all major weldments. Commercial items such as the Belleville disk springs were checked during the selection process to ensure suitability.

3.1 Drive

Results of finite element analysis on the wheel weldment using Autodesk Inventor software are shown in Figure 5. These results were checked with ANSYS software, using an identical set of constraints. Assuming bonded contacts, the maximum stress was found to be 16.23 ksi, found only at the edges of bolt holes. Even with these stress concentration areas, the maximum stress is acceptable and indicates a factor of safety of more than two. The displacement was found to be less than 1/16 of an inch under maximum loads, also an acceptable amount.

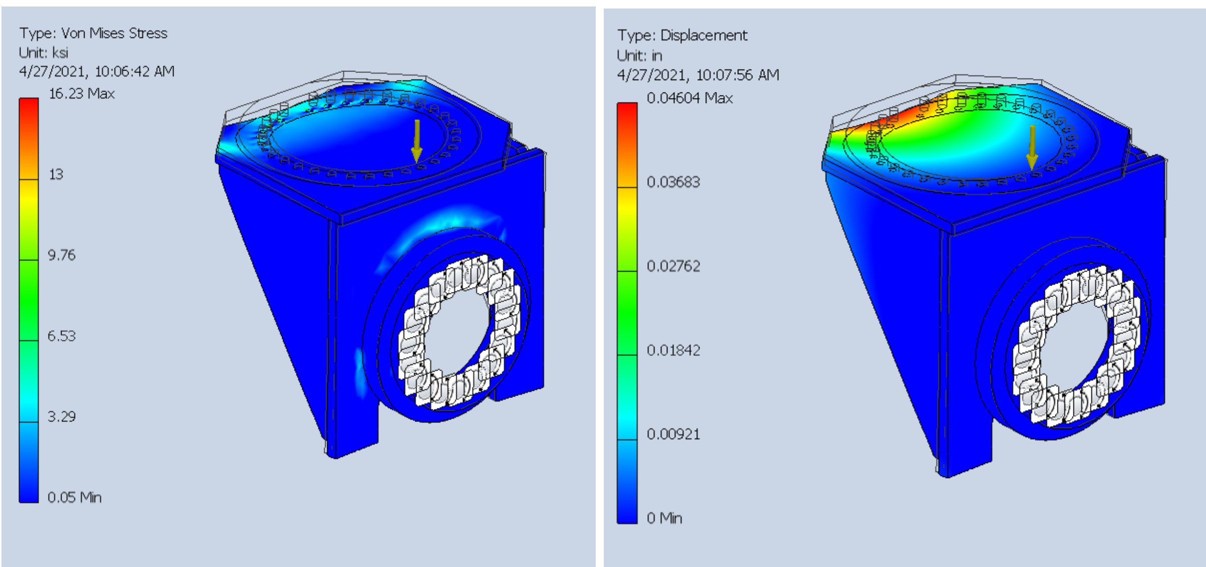


Figure 5- Von Mises Stress (Left) and Displacement (Right)

3.2 Frame and Coil Holder

Similarly to the wheel weldment, a finite element analysis was performed on both the main frame and coil holder. Autodesk Inventor results are shown in Figures 6 and 7. The maximum stresses and displacements in these large weldments are slightly less than that of the wheel weldment. Once again, the highest stresses occur at obvious stress concentrations and the results are acceptable. Hand calculations were also done to check the stress in one of the beams in the frame in order to confirm the computer results.

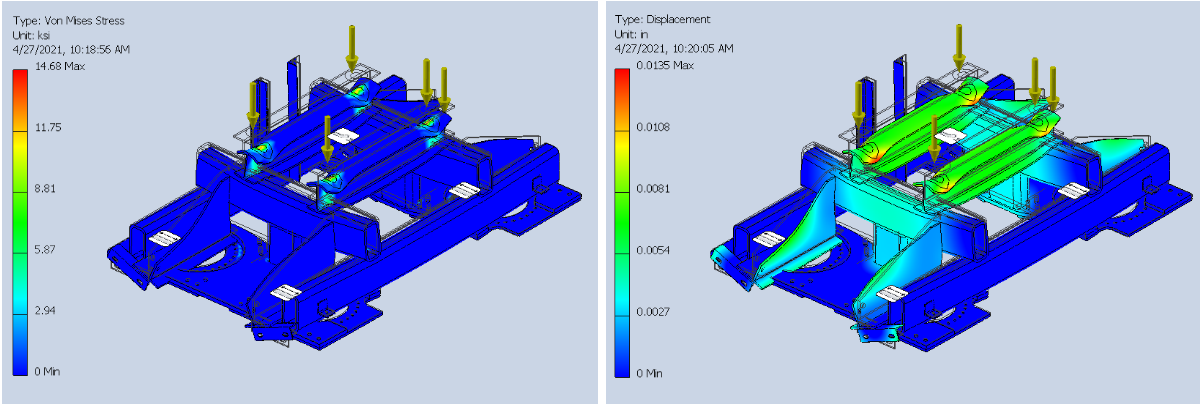


Figure 6- Von Mises Stress (Left) and Displacement (Right)

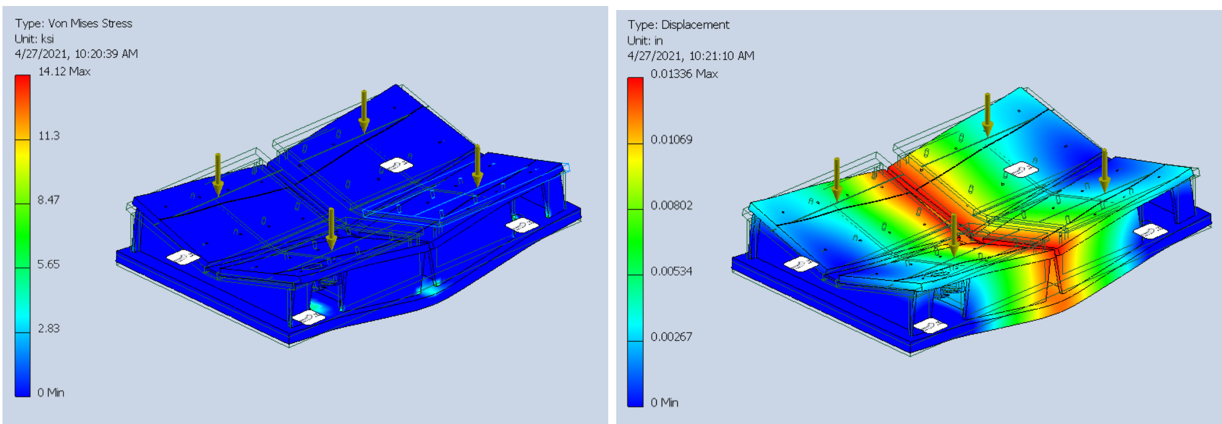


Figure 7- Von Mises Stress (Left) and Displacement (Right)

3.3 Battery and Charging

Batteries were selected after calculation of battery life, which calculation can be found in appendix D. The final result from these calculations was 4.9 KwH, which is for a 504 second cycle and 3092 seconds at rest, for a total of 8 cycles per day. This exceeds the expected usage time, but was chosen to keep the battery life above what was necessary for operation, as battery life deteriorates over time.

4. Costs

Table 8- Initial Estimated Production Cost

Initial Estimated Production Cost				
	Materials	Time	Total	Margin
Frame	$85,971.20	$168,000.00	$253,971.20	22.25%
Drive Commercial Parts	$164,806.50	$10,500.00	$175,306.50	
Electrical Components	$30,000.00	$31,500.00	$61,500.00	
			$490,777.70	$600,000.00

Table 9- Final Estimated Production Cost

Final Estimated Production Cost				
	Materials	Time	Total	Margin
Frame	$25,813.60	$44,437.50	$70,251.10	20.00%
-Main Weldment	$10,503.20			
-Platten	$5,148.00			
-Charging Pad Arm	$252.00			
-Motor Shield (x2)	$620.00			
-Cow Catcher (x2)	$1,072.00			
-Wheel Weldment (x4)	$6,592.00			
-Steer Motor Plate (x4)	$1,626.40			
Drive Commercial Parts	$82,403.25	$3,703.13	$86,106.38	
-Steer Motor (x4)	$32,384.00			
-Wheel Motor (x4)	$31,400.00			
-Wheel (x4)	$18,619.25			
Electrical Components	$34,854.56	$11,109.38	$45,963.94	
-Battery (x2)	$14,674.00			
-Control Cabinet	$527.56			
-Inductive Charging System	$10,000.00			
-Obstacle Detecting Sensor (x2)	$8,130.00			
-Coil Detect Sensor	$228.00			
-Wiring and Magnetic Strip	$1,295.00			
Other	$916.86	$11,850.00	$12,766.86	
-Disc Spring (x16)	$113.92			
-Fasteners (Various Sizes)	$802.94			
			$215,088.27	$258,105.92

Table 10- Total Cost

Total Cost		
	Cost	
AGV	$258,105.92	
2 Workers	$25,000.00	per year
Years of Operation		
1	$283,105.92	
5	$383,105.92	
8	$458,105.92	

Table 11- Alternative Cost

Alternative Cost		
	Cost	
3 Car	$1,350,000.00	
2 Saddle	$150,000.00	
3 Workers	$37,500.00	per year
Years of Operation		
1	$1,537,500.00	
5	$1,687,500.00	
10	$1,875,000.00	

Table 12- Cost Savings

Cost Savings	
1	$1,254,394.08
5	$1,304,394.08
Lifetime	$1,416,894.08
per year	$12,500.00

4.1 Parts

In Tables 8 and 9 above, the cost estimations done for the AGV can be seen. Because of time constraints, the frames were not sent out for quote. This was due to the high labor time of creating full drawings, while also needing to be completed early enough for quotes to be returned. The team decided it was in the best interest of the project to continue using a cost estimation for these components. This was done with help from the industrial advisor to the project. The calculated total cost of the AGV was much lower than originally expected. Table 8 estimates a total cost of the AGV before design, and Table 9 shows our itemized cost estimate, approximately half of the original estimate.

4.2 Labor

Labor costs are estimated based on the hours for both design and manufacture of components. Labor is estimated as $70 per hour of labor, based on the costs for management, engineering, and manufacturing, as well as facility, tool use, and other expenses. This estimation was used based on the recommendation of the industry advisor. This cost can be seen in the second cost column, labeled "Time", in Tables 8 and 9. Labor estimates are lower for the AGV design, giving the best scenario for the standard design. This results in $70 per hour of savings, or approximately $12,500.00 per year (Table 12) based on the expected usage of the line.

4.3 Cost Conclusions

Tables 10 through 12 show the most useful data for the cost analysis. These tables analyze the costs of an AGV system, as designed by this team, as well as the alternative standard system. As you can see from tables 10 and 11, the expected lifespan of the AGV is lower than the standard system. This is primarily due to the uncertainty in the new design. SES has manufactured many systems using the standard methods, so the confidence in those systems is higher. Working with SES, the team determined 8 years was reasonable as an initial estimate for lifespan of the AGV and 10 years for the standard system. In Table 12, the cost savings for using the AGV over various time spans is shown. Because the capital and labor costs are lower for the AGV, the AGV is less expensive initially and over time, including at the end of expected life of the systems.

5. Conclusion

5.1 Accomplishments

In appendix A, the list of system requirements and verifications can be found. Overall, our team was able to accomplish the majority of the objectives. Our team was able to fully model the AGV, including selection and models of commercial parts. However, drawings of the weldments were not able to be produced in time to use for cost analysis. All necessary calculations were done, and two FEA analyses were performed, supporting the calculations. The team was also able to produce a manual of commercial parts for maintenance of the machine.

5.2 Uncertainties

The exact layout of the facility was unknown. To compensate, a facility layout which would potentially use an AGV was used. This same method was used to determine the coil specifications. Required cycle times assumed 8 uses per day, which is reasonable for a low throughput line in a facility. As noted in the cost section above, the life of the AGV is unknown because none have been produced before. Weldments required were not quoted for price. However, prices will fluctuate over time, so the final cost given above is only to be taken as a rough estimate and not valid as a quote. Installation costs particular to the facility, such as altered foundations and electrical wiring required for the function of the systems is not included in the scope of the project. The customer would be consulted for the takeover point to be determined.

5.3 Ethical considerations

The primary ethical considerations were covered in the safety section. Calculations were done, and confirm that the cameras are able to detect an obstruction or person and signal to stop in time for the stop to be completed. In addition, a manual control for the AGV will be included, to allow for emergency stops or operation outside standard bounds. Other ethical considerations include complying to applicable engineering standards.

5.3.1 Engineering Standard Compliance

Complying to applicable standards is critical to good engineering. SES has not produced an AGV before, so discovering the applicable standards was part of our design process. SES standards were used for the calculations, especially factors of safety. ANSI/ITSDF B36.5-2019 (Rev 5-18-20) was used for determining specific requirements. According to section 4.3.1, “The prime consideration is that the braking system in conjunction with the object detection system and the response time of the safety control system shall cause the vehicle to stop prior to impact between the vehicle structure and other mounted equipment, including its intended load, and an obstruction being sensed in advance of the moving vehicle in the main direction of travel. (see Sections III, para. 8.7.1 (c) (2) and para 8.11).” Additionally, floor markings indicating the path of the AGV across its width will be installed, in addition to the magnetic strip. Crossing over towards customer responsibilities, according to section 6.3, general training is required for operators of the vehicle. A nameplate will also be required, using information available from the manual and model to label the vehicle (ANSI, 2019).

5.4 Future work

Future work for this project would include mostly electrical engineering. Selection of controller and design or purchase of a system to use the sensors would be the major details left to design for this. Design of the final product for a proposed design would require design of the path for the AGV to follow, and possible adjustments to the frame or drive of the AGV, depending on the requirements for the new application. This would primarily be an increase in the size of drive motors or strength of the frame, to accommodate a larger coil. The goal of this project was to generate a base design to modify from depending on the individual applications, so this future work was kept in mind throughout the design process. Because of the work put in while designing the AGV, the design can be copied and modified easily for future projects involving AGV design.

References

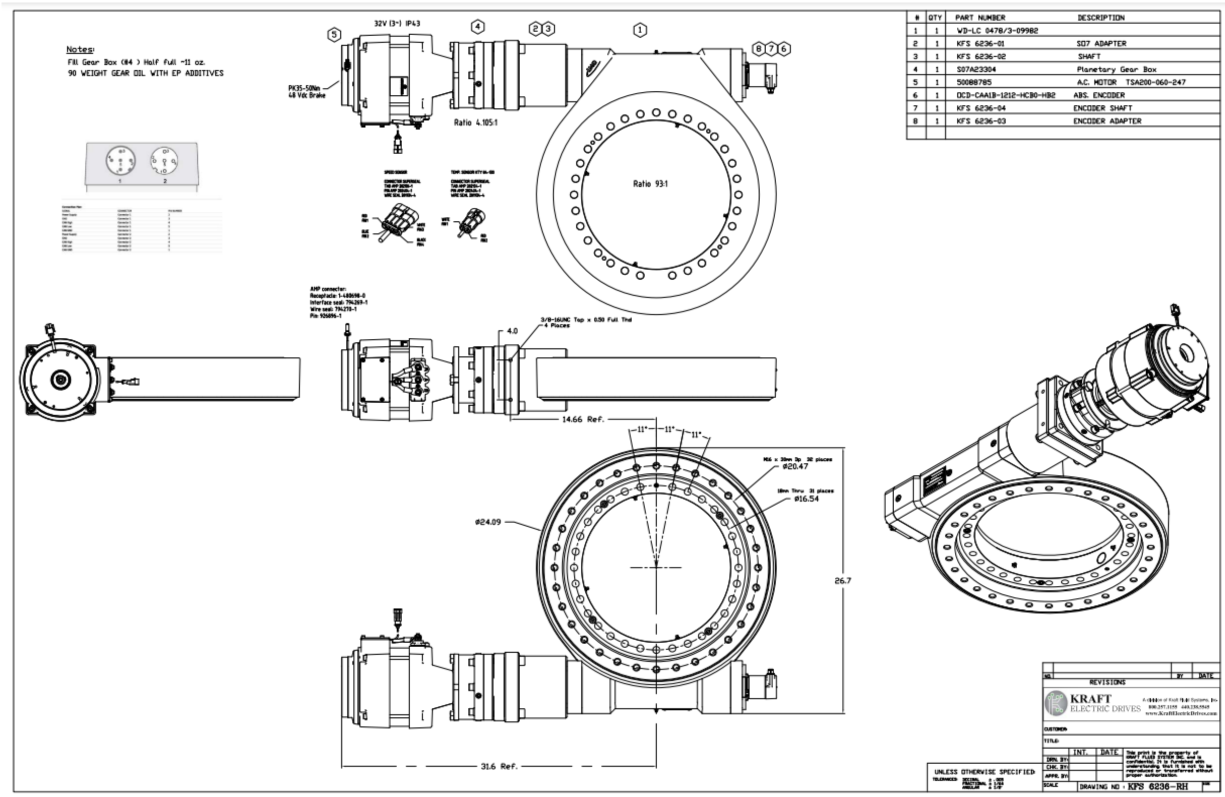
ANSI/ITSDF. (2019). *SAFETY STANDARD FOR DRIVERLESS, AUTOMATIC GUIDED INDUSTRIAL VEHICLES AND AUTOMATED FUNCTIONS OF MANNED INDUSTRIAL VEHICLES* (B56.5). Retrieved from http://www.itsdf.org/cue/b56-standards.htm

Appendix A Requirement and Verification Table

System Requirements and Status Verification

Requirement	Verification status (Y or N)
1. Modeling	Y
a. Commercial Item Selection	Y
b. Drawing	N
2. Calculation	Y
a. Coil Accommodation	Y
b. FEA and Verification	Y
3. Cost Analysis	Y
a. Weldment Quotes	N
4. Manual	Y

Appendix B Manual Information



Part No. D703554

D703554 - Disc Springs to DIN 2093

Definition and Description | Estimating Fatigue Life | Tolerances

The standard protective surface treatment is phosphate and oiled however superior surface treatments should be considered for disc springs that are to be situated in hostile environments.

DIN 2092/2093 disc springs are manufactured to close tolerances and are made from high quality spring steel strip and forgings.

The disc springs are pre-stressed (scragged) and the machining and radiusing of the inside and outside diameters remove stress raisers which could otherwise reduce disc spring fatigue life.

Category: Disc Springs DIN 2093 SKU: D703554

ADDITIONAL INFORMATION

Outside Dia	70
Inner Dia	35.5
Thick	4
Cone Ht	1.8
Total Ht	5.8
Thick Ratio	0.45
Wt per 1000	90

3/17/2021 Part No. D703554 - Disc Springs DIN 2093 from Belleville Springs

HOME PRODUCTS DISC SPRING INFO MATERIALS & FINISHES CONTACT

ADVANCED SEARCH

15% Def : Stress δIII N/mm²	294
30% Def : mm	0.54
30% Def : Force N	10393
30% Def : Stress δII N/mm²	523
30% Def : Stress δIII N/mm²	573
45% Def : mm	0.81
45% Def : Force N	15115
45% Def : Stress δII N/mm²	821
45% Def : Stress δIII N/mm²	837
60% Def : mm	1.08
60% Def : Force N	19604
60% Def : Stress δII N/mm²	1142
60% Def : Stress δIII N/mm²	1085
75% Def : mm	1.35
75% Def : Force N	23923
75% Def : Stress δII N/mm²	1486
75% Def : Stress δIII N/mm²	1319
90% Def : mm	1.62
90% Def : Force N	28137
90% Def : Stress δII N/mm²	1855
90% Def : Stress δIII N/mm²	1537

Wall-Mount Enclosures
Type 4 Single-Door
Data Sheet

Application
- Houses electrical controls and instruments
- Intended for indoor or outdoor use
- Protects against windblown dust and rain, splashing water and hose directed water

Standards
- UL 508A listed, Type 4, Type 12 and Type 13
- CSA C22.2 No.94 certified, Type 4, Type 12 and Type 13
- Conforms to NEMA standard for Type 4, Type 12 and Type 13

Finish
- Wash and phosphate undercoat
- ANSI 61 gray polyester powder finish

Accessories
- Panels
- NEMA terminal strap kit
- Terminal blocks
- Door lock kit
- Floor stand kit
- Touch-up paint
- See Accessories section

Construction
- Enclosure and door are fabricated from code gauge steel, (see table, page 144)
- All continuous welded seams are finished smooth
- Doors are secured to the body with a heavy-duty continuous hinge on one side and easy-to-release stainless steel door clamps mounted to the other three sides
- Ground stud provided on door and body
- Formed lip around enclosure opening diverts liquids and contaminants
- Each door has a padlock hasp with sealing hole provision
- Print pocket provided
- Door has a seamless poured in-place gasket
- .375-16 collar studs are provided for mounting optional panel
- External mounting feet are provided for secure wall mounting

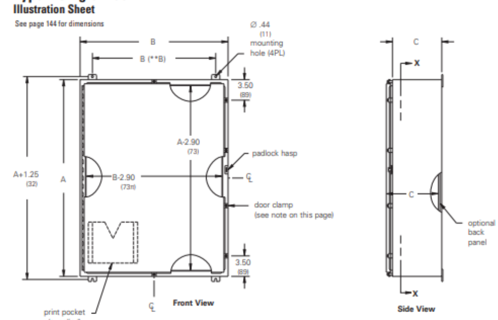
Discount Schedule: C2

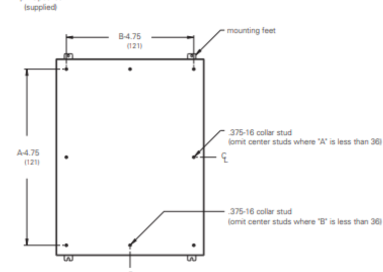
Subclass: DF0

Notes: We can provide special sizes, finishes and other modifications. Consult the factory for your special requirements.

Wall-Mount Enclosures
Type 4 Single-Door
Illustration Sheet

See page 144 for dimensions



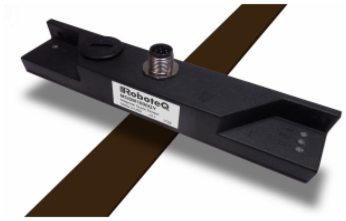


Section X-X

Notes: Dimensions: **B = (-2.50) if 12 inches wide; (-6.00) if wider than 12 inches. Clamps are mounted along three sides of the enclosure door. Spacing between clamps along side opposite the hinge does not exceed 15 inches.
Dimensions are in inches. Millimeters shown are for reference only. Data subject to change without notice.

RoboteQ **MGSM1600GY**

Precision Magnetic Track Following Sensor with Gyrosope



The MGSM1600GY is a magnetic guide sensor capable of detecting and reporting the position of a magnetic field along its horizontal axis. The sensor is intended for line following robotic applications, using a magnetic tape to form a track guide on the floor.

The sensor uses advanced signal processing to accurately measure its lateral distance from the center of the track, with millimeter resolution, resulting in nearly 160 points end to end. Tape position information can be output in numerical format on the sensor's RS232 or USB ports. The position is also reported as a 0 to 3V voltage output and as a variable PWM output. Additionally, the sensor supports a dedicated MultiPWM mode allowing seamless communication with all Roboteq motor controllers using only one wire.

The sensor will detect and manage 2-way forks. It can be instructed to follow the left or right track using commands issued via the serial/USB. All of the sensor's operating parameters and commands are also accessible via its CAN bus interface.

In addition to detecting a track to follow, the sensor will detect and report the presence of magnetic markers that may be positioned on the left or right side of the track. The sensor is equipped with four LED indicator lights for easy monitoring and diagnostics.

The MGSM1600GY has a 3-axis Gyroscope that can be used to provide additional stability and guidance to the vehicle.

The sensor incorporates a high performance, Basic-like scripting language that allows users to add customized functionality to the sensor. A PC utility is provided for configuring the sensor, capturing and plotting the sensor data on a strip chart recorder, and visualizing in real time the magnetic field as it is seen by the sensor.

The sensor firmware can be updated in the field to take advantage of new features as they become available.

Applications

- Automatic Guided Vehicles
- Automated warehouses
- Automated shelf restocking systems
- Material conveying robots
- Flexible assembly lines

Key Features

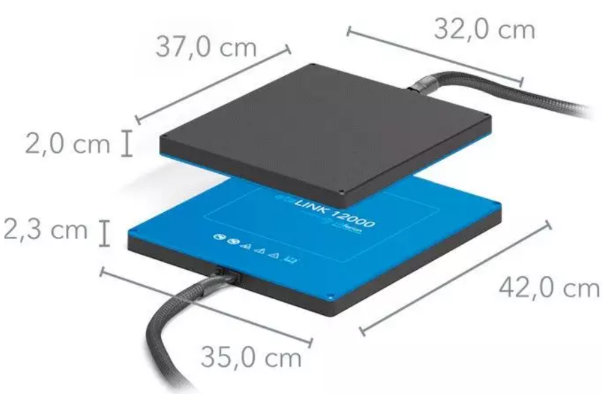
- Detects and measures position of magnetic track along horizontal axis
- Optimized for use with 25mm or 50mm wide adhesive magnetic tape
- 10mm to 60mm operating height
- 160mm sensing width with 1mm resolution
- Selectable, North or South on top, magnetic polarity of track
- Capable of detecting and managing 2-way fork/merges
- Detection of magnetic "markers" of inverted polarity at left or right of main track
- Three Axis MEMS Gyroscope with selectable range
- Simple interface to most PLC brands and to micro-computers
- Direct and seamless interface to Roboteq motor controllers
- 100Hz update rate
- Status LEDs for tape and marker detection
- Digital outputs for "tape present" and left/right marker detection
- Numerical Tape position data output on RS232 or USB ports
- Tape position on PWM output at 250Hz or 500Hz
- Tape position on 0-3V analog output
- CAN interface up to 1Mbit/s

- Built-in programming language for optional local processing of tape and marker data
- Easy configuration, testing and monitoring using provided PC utility
- Field upgradeable software for installing latest features via the Internet
- Waterproof M12, 8-pin connector
- Wide range 4.5V to 30V DC operation
- 165 mm wide x 30 mm deep x 25 mm tall
- -40o to +85o C operating environment
- IP64 rated enclosure. Resistant to water splash

Orderable Product References

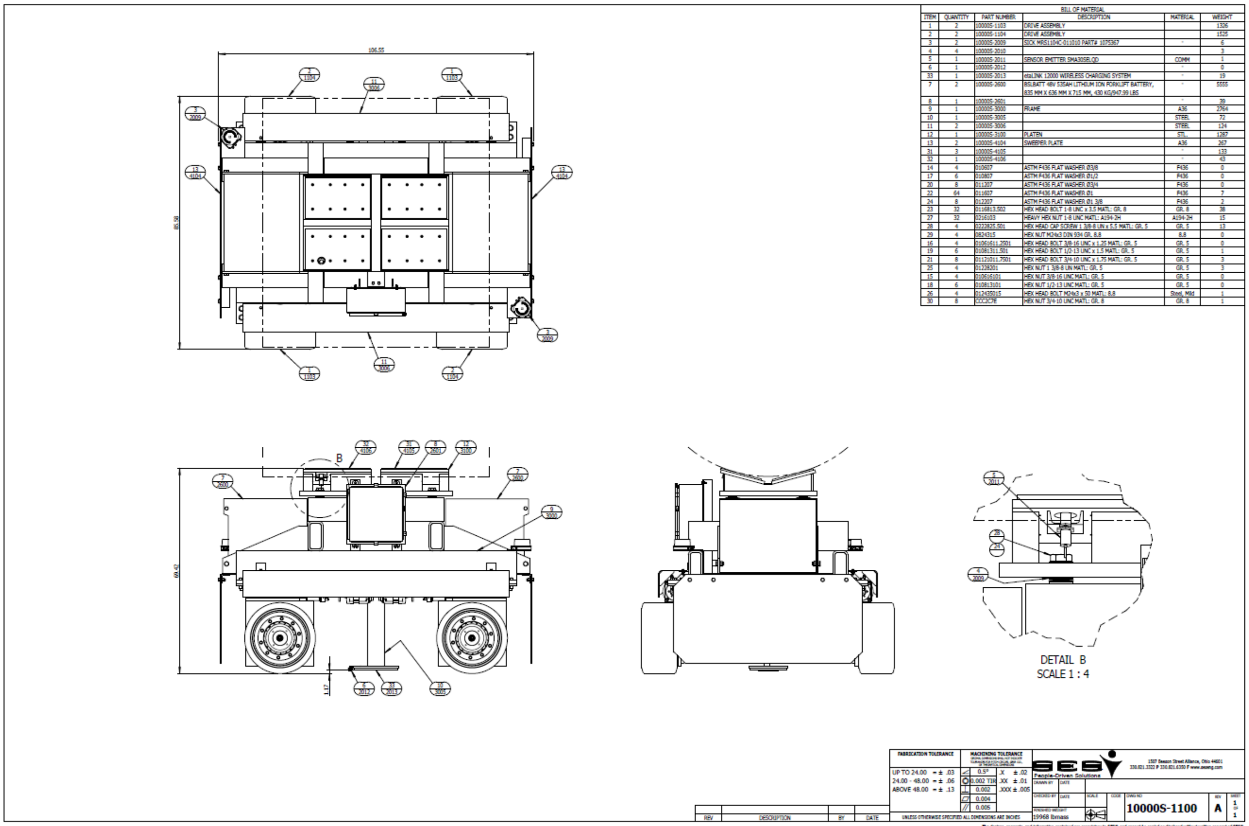
Reference	Description
MGSM1600GY	Magnetic guide sensor, 3-axis Gyroscope, serial, USB, analog, PWM, CAN, M12 Connector
MTAPE25NR	25 mm wide magnetic tape for MGSM1600GY with North top side. 50m (150ft) roll
MTAPE50NR	50 mm wide magnetic tape for MGSM1600GY with North top side. 50m (150ft) roll

Specifications etaLINK 12000



etaLINK 12000	
Continuous charging power	12000 W
Charging voltage	15 – 120 V
Charging current	100 – 400 A
Protection class	IP65 und IP68
Optimum distance	15 – 40 mm
Position tolerance	+/– 70 mm

Appendix C Assembly Drawing



BILL OF MATERIAL

ITEM	QUANTITY	PART NUMBER	DESCRIPTION	MATERIAL	WEIGHT
1	2	100005-1103	DRIVE ASSEMBLY		1326
2	2	100005-1104	DRIVE ASSEMBLY		1525
3	2	100005-2009	SICK MRS1104C-011010 PART# 1075367	-	6
4	4	100005-2010			3
5	1	100005-2011	SENSOR EMITTER SMA30SELQD	COMM	1
6	1	100005-2012		-	0
33	1	100005-2013	etaLINK 12000 WIRELESS CHARGING SYSTEM	-	19
7	2	100005-2600	BSLBATT 48V 535AH LITHIUM ION FORKLIFT BATTERY, 835 MM X 636 MM X 715 MM, 430 KG/947.99 LBS	-	5555
8	1	100005-2601		-	39
9	1	100005-3000	FRAME	A36	2764
10	1	100005-3005		STEEL	72
11	2	100005-3006		STEEL	124
12	1	100005-3100	PLATEN	STL.	1287
13	2	100005-4104	SWEEPER PLATE	A36	267
31	3	100005-4105		-	133
32	1	100005-4106		-	43
14	4	010607	ASTM F436 FLAT WASHER Ø3/8	F436	0
17	6	010807	ASTM F436 FLAT WASHER Ø1/2	F436	0
20	8	011207	ASTM F436 FLAT WASHER Ø3/4	F436	0
22	64	011607	ASTM F436 FLAT WASHER Ø1	F436	7
24	8	012207	ASTM F436 FLAT WASHER Ø1 3/8	F436	2
23	32	0116813.502	HEX HEAD BOLT 1-8 UNC x 3.5 MATL: GR. 8	GR. 8	38
27	32	0216103	HEAVY HEX NUT 1-8 UNC MATL: A194-2H	A194-2H	15
28	4	0222825.501	HEX HEAD CAP SCREW 1 3/8-8 UN x 5.5 MATL: GR. 5	GR. 5	13
29	4	0824315	HEX NUT M24x3 DIN 934 GR. 8.8	8.8	0
16	4	01061611.2501	HEX HEAD BOLT 3/8-16 UNC x 1.25 MATL: GR. 5	GR. 5	0
19	6	01081311.501	HEX HEAD BOLT 1/2-13 UNC x 1.5 MATL: GR. 5	GR. 5	1
21	8	01121011.7501	HEX HEAD BOLT 3/4-10 UNC x 1.75 MATL: GR. 5	GR. 5	3
25	4	01228201	HEX NUT 1 3/8-8 UN MATL: GR. 5	GR. 5	3
15	4	010616101	HEX NUT 3/8-16 UNC MATL: GR. 5	GR. 5	0
18	6	010813101	HEX NUT 1/2-13 UNC MATL: GR. 5	GR. 5	0
26	4	012435015	HEX HEAD BOLT M24x3 x 50 MATL: 8.8	Steel, Mild	1
30	8	CCC2C7E	HEX NUT 3/4-10 UNC MATL: GR. 8	GR. 8	1

Appendix D Calculations

SENIOR DESIGN CALCULATIONS - PAGE 1

CALCULATE MOTOR H.P.

$W\_coil := 40000$ lbs (LIVE LOAD - MAX)

$W\_car := 27000$ lbs (DEAD LOAD - ESTIMATE)

$V := 40$ ft/min (MAX VELOCITY)

$V2 := \frac{V}{60} = 0.667$ ft/s

$t := 4$ s (TIME TO MAX VELOCITY)

$a := \frac{V2}{t} = 0.167$ ft/s^2 (MAX ACCELERATION)

$R.R. := \frac{20}{2000} \cdot (W\_coil + W\_car) = 670$ lbs (ROLLING RESISTANCE)

$F := \frac{W\_coil + W\_car}{32.17} \cdot a + R.R. = 1.017 \cdot 10^3$ lbs (FORCE REQUIREMENT @ GROUND)

$d\_wheel := 24$ in (WHEEL DIAMETER)

$r\_wheel := \frac{d\_wheel}{2}$ (WHEEL RADIUS)

$T := F \cdot r\_wheel = 1.221 \cdot 10^4$ in-lbs (TORQUE REQUIREMENT)

$T := \frac{T}{0.9} = 1.356 \cdot 10^4$ in-lbs (TORQUE W/ S.F.)

$RPM := \frac{V}{\pi \cdot d\_wheel} = 0.531$ rev/min (WHEEL RPM REQUIREMENT)

$HP1 := \frac{T \cdot RPM}{63025} = 0.114$ HP (HORSEPOWER REQUIREMENT)

$HP2 := \frac{F \cdot V}{33000} = 1.233$ HP (STEADY STATE HORSEPOWER)

$HP2 > HP1$

$HP := HP2 = 1.233$ HP (HORSEPOWER REQUIREMENT)

$m := 20000\ \mathbf{lbm}$ Mass of the assembly

$a := 0.5\ \dfrac{\mathbf{ft}}{\mathbf{s}^2}$ $v := 150\ \dfrac{\mathbf{ft}}{min} = 2.5\ \dfrac{\mathbf{ft}}{\mathbf{s}}$ $t := \dfrac{v}{a} = 5\ \mathbf{s}$ Start/stop time

$d := v \cdot t - 0.5 \cdot a \cdot t^2 = 6.25\ \mathbf{ft}$ start/stop distance

$h := 42.27\ \mathbf{in} = 3.523\ \mathbf{ft}$ Center of mass to ground

$M_b := h \cdot a \cdot m = \left(3.523 \cdot 10^4\right)\ \dfrac{\mathbf{lb} \cdot \mathbf{ft}^2}{\mathbf{s}^2}$ Moment due to braking

$l := 32.5\ \mathbf{in} = 2.708\ \mathbf{ft}$ Distance from center of mass to wheel

$M_g := l \cdot 32.2\ \dfrac{\mathbf{ft}}{\mathbf{s}^2} \cdot m = \left(1.744 \cdot 10^6\right)\ \dfrac{\mathbf{lb} \cdot \mathbf{ft}^2}{\mathbf{s}^2}$ Moment due to gravity

$M_b < M_g = 1$ True: no tipping by 2 orders of magnitude

Product Selection

<u>Belleville Disc Spring</u>

$W\_Coil := 40000$ lbs

$W\_Platten := 1500$ lbs

$$F := \frac{(W\_Coil + W\_Platten) \cdot 4.4482}{4} = 4.615 \cdot 10^4$$ N (Required spring force @ 75% deflection)

Using 2 disc springs in parallel and 2 in series

$$F := \frac{F \cdot 1.03}{2} = 2.377 \cdot 10^4$$ N (Required spring force @ 75% deflection)

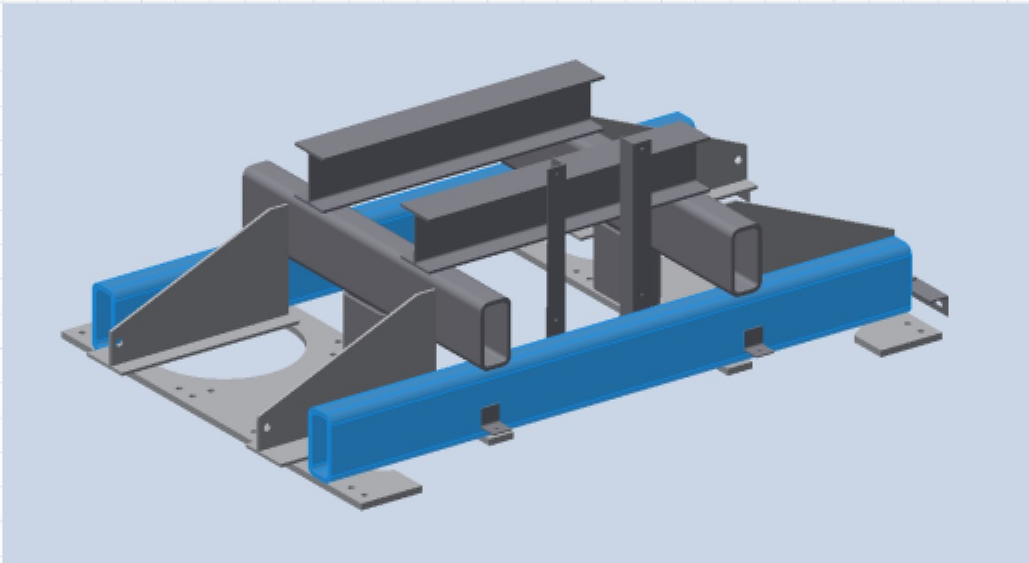
Choose D703554
OD = 70 mm
ID = 35.5 mm
t = 4 mm
75% def = 1.35 mm
Force @ 75% def = 23,923 N

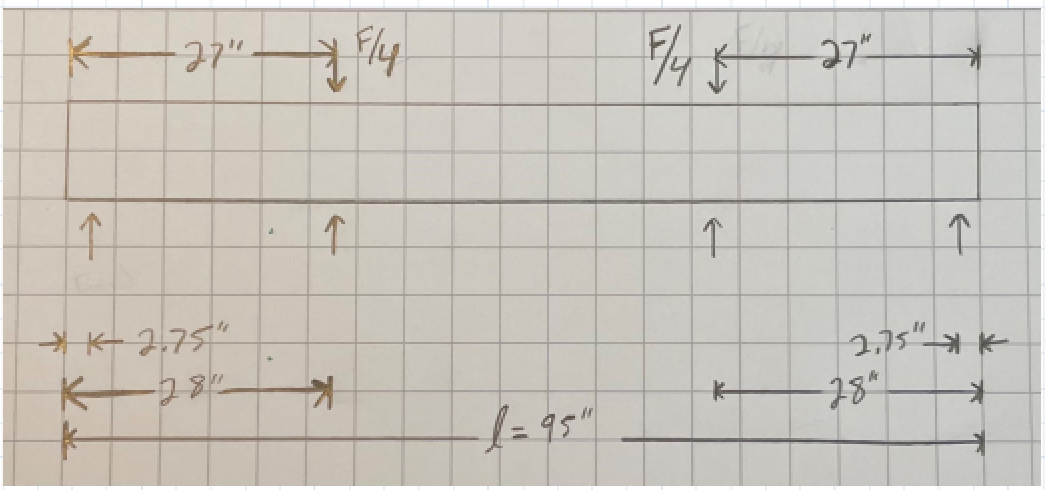
Browse for Image...

Browse for Ima

Frame Calculations - 2/22/21

Beam 1 - Rectangular Tube (A500)





$h := 10$ in

$b := 5$ in

$t := 0.625$ in

$I := 207.32$ in^4

$Q := 41.46$ in^3

$A := 16.18$ in^2

$E := 29000$ ksi

$W\_Coil := 40000$ lbs

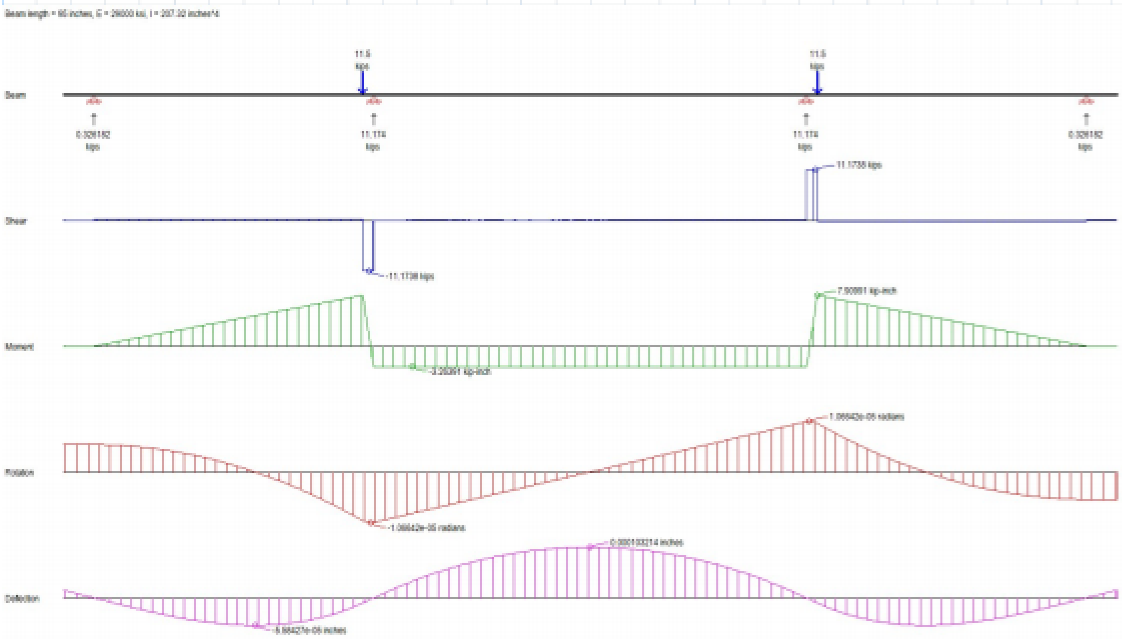
$W\_Car := 6000$ lbs (above beam)

$F := W\_Coil + W\_Car = 4.6 \cdot 10^4$ lbs

$\sigma\_ut := 58$ ksi

$\sigma\_y := 42$ ksi

$N\_d := 3$



$M := 7.91$ kip-in

$V := 11.17$ kips

$c := \frac{h}{2} = 5$ in

<u>Static Stress Check</u>

$\sigma\_B := \frac{M \cdot c}{I} = 0.191$ ksi

$\sigma\_B\_Max := \frac{1.1 \cdot \sigma\_y}{N\_d} = 15.4$ ksi

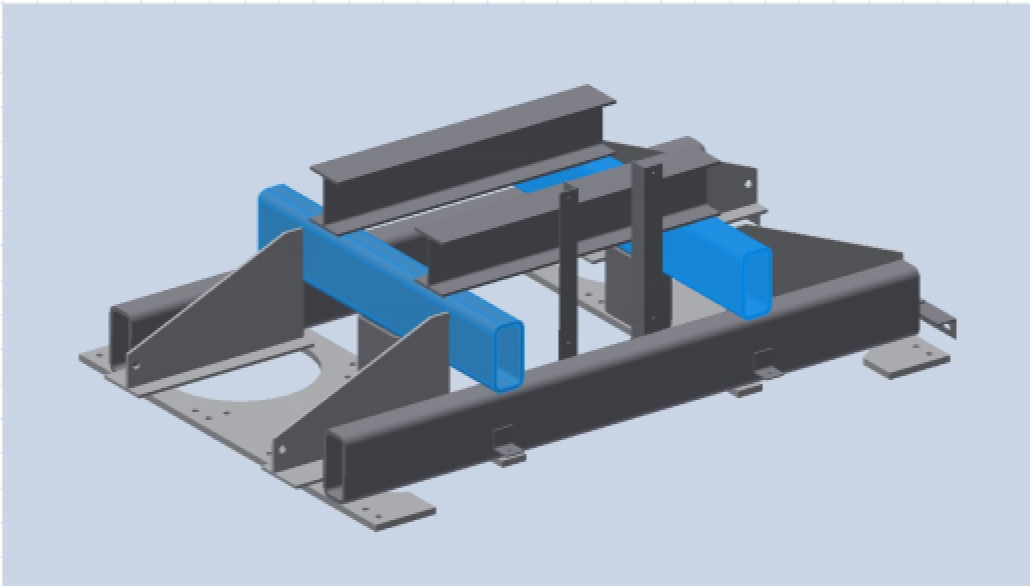
$\sigma\_B < \sigma\_B\_Max$

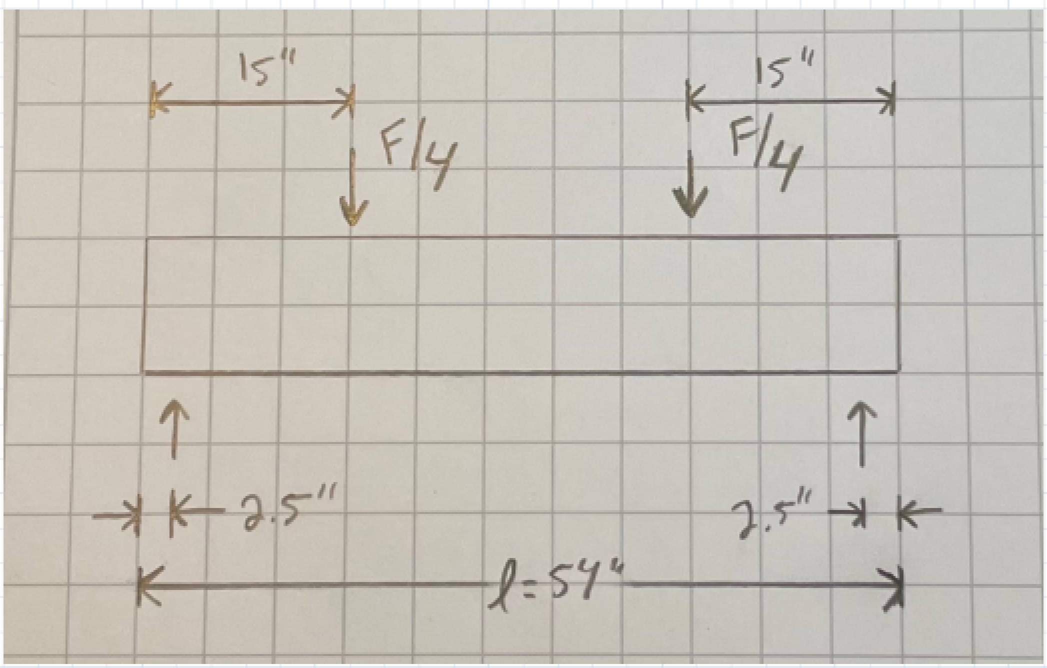
$\tau\_V := \frac{V \cdot Q}{I \cdot t} = 3.574$ ksi

$\tau\_V\_Max := \frac{\sigma\_y}{N\_d \cdot \sqrt{3}} = 8.083$ ksi

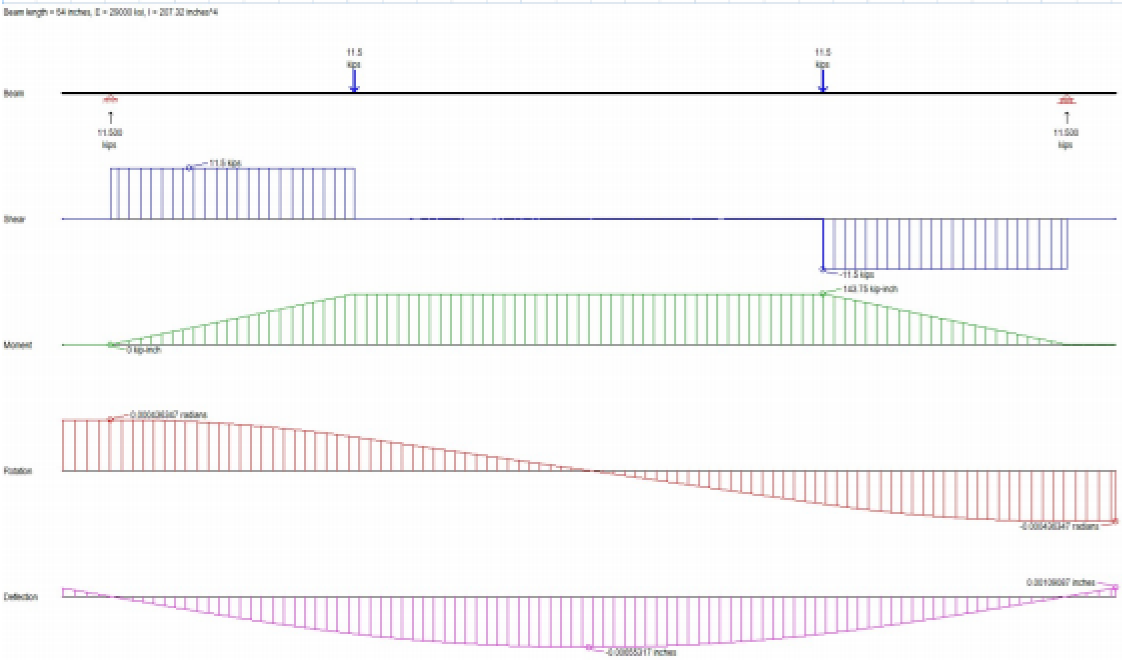
$\tau\_V < \tau\_V\_Max$

Beam 2 - Rectangular Tube (A500)





$h2 := 10$ in
$b2 := 5$ in
$t2 := 0.625$ in
$I2 := 207.32$ in^4
$Q2 := 41.46$ in^3
$A2 := 16.18$ in^2
$E2 := 29000$ ksi



$M2 := 143.75$ kip-in
$V2 := 11.5$ kips

$c2 := \frac{h2}{2} = 5$ in

<u>Static Stress Check</u>

$\sigma\_B := \frac{M2 \cdot c2}{I2} = 3.467$ ksi

$\sigma\_B\_Max := \frac{1.1 \cdot \sigma\_y}{N\_d} = 15.4$ ksi

$\sigma\_B < \sigma\_B\_Max$

$\tau\_V := \frac{V2 \cdot Q2}{I2 \cdot t2} = 3.68$ ksi

$\tau\_V\_Max := \frac{\sigma\_y}{N\_d \cdot \sqrt{3}} = 8.083$ ksi

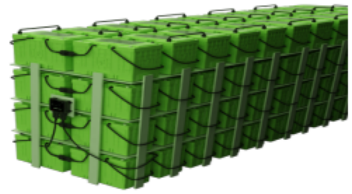
$\tau\_V < \tau\_V\_Max$

Battery Calculation Spreadsheet

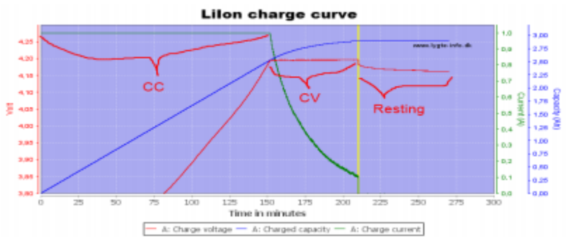
Enter Data in Green Cells

Combined motor Horsepower:	100	HP
Estimated Hotel Load:	500	Watts
Req Power @ Full Load: (746 Watts/HP)	74600	Watts
Req Power @ Acceleration + Hotel Load:	112400	Watts
Req Power @ Steady State Motion + Hotel Load:	37800	Watts
Accel Time to Full speed:	4	seconds
Time at Full Spee	500	seconds
Time at Rest	3092	seconds
Total System Cycle Time	3596	seconds
Total Energy Use Per cycle:	5762.111111	Watt-Hr
Use Time:	8	Hrs
# of Cycles during designated Use time:	8.008898776	Cycles
Total Pack Energy Required:	46.14816463	KwH
Price per KwH	$0.10	$
Total Pack size with Charging	4.8756396	KwH
Cost per year	$5,053.22	$
Diesel Cost per	$183,960.00	$

6.13



Charge While resting?	YES	Average Charge Rate	6	Kw
		Total wH charge during rest	5153.3333	Watt-Hr



Drop Down Options:
Charging

YES

NO

Voltage

480

230

www.pluglesspower.com
www.valence.com

www.currentways.com

	Product	Voltage	Capacity	Weight	Dimensions	BCI Group Number	Max. Cont. Current	Charge Voltage	Energy
	U1-12XP	12V	40Ah	6.5 kg/ 14.3 lbs	7.76" x 5.12" x 7.17" 197mm x 131mm x 182mm	U1R	80A	14.6V	512 Wh
	U24-12XP	12V	110Ah	15.8 kg/ 34.8 lbs	10.2" x 6.77" x 8.86" 260mm x 172mm x 225 mm	Group 24	150A	14.6V	1408 Wh
	U27-12XP	12V	138Ah	19.5 kg/ 42.9 lbs	12.0" x 6.77" x 8.86" 306mm x 172mm x 225 mm	Group 27	150A	14.6V	1766 Wh
	UEV-18XP	18V	69Ah	14.9 kg/ 32.8 lbs	10.6" x 5.83" x 9.65" 269mm x 148mm x 245mm	-	120A	21.9V	1325 Wh
	U27-24XP	24V	69Ah	18.6 kg/ 40.9 lbs	12.0" x 6.77" x 8.86" 306mm x 172mm x 225 mm	Group 27	140A	29.2V	1766 Wh
	U27-36XP	36V	46Ah	19.6 kg/ 43.1 lbs	12.0" x 6.77" x 8.86" 306mm x 172mm x 225 mm	Group 27	90A	43.8V	1766 Wh

https://www.lithiumforkliftbattery.com/Lithium-Ion-Forklift-Batteries.html

Part	Series Qty	Voltage	Pack Output Voltage	Series Current(A)	Parrallell Strings		Total Pack Current	Approx Price Per Battery	Total Batterys	Pack Cost	Batt Kwh	Pack Kwh
UEV-18XP	16	18	288	120	4		480	1170	64	74880	1.33	85.12
U27-36XP	8	36	288	90	4		360	1365	32	43680	1.77	56.64
U27-24XP	12	24	288	140	4		560	1365	48	65520	1.77	84.96